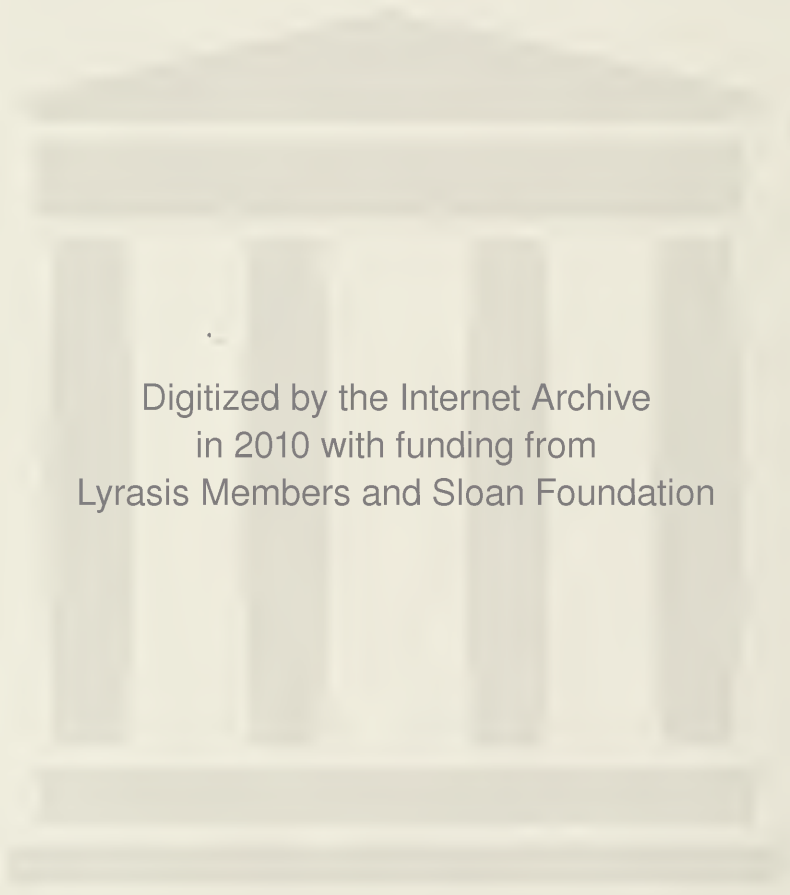


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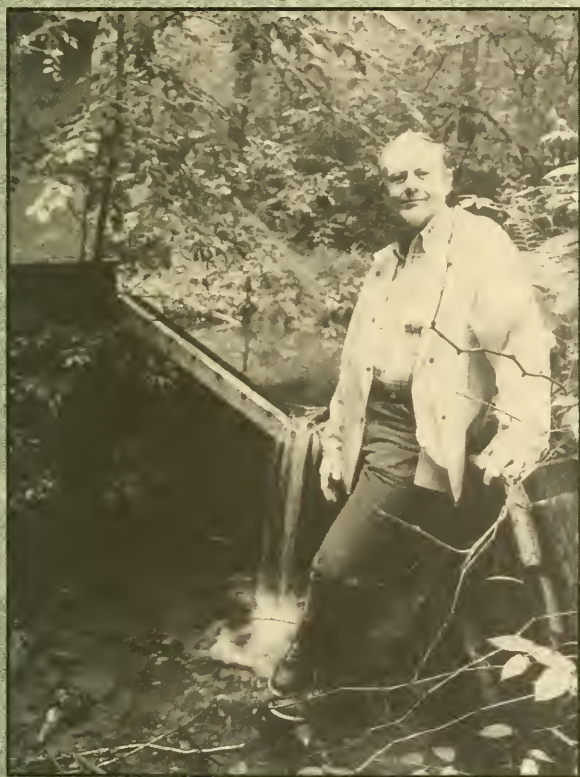


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Nutrient Fluxes for Two Small Watersheds: Seven-Year Results from the West Virginia University Forest



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West Virginia University
Agricultural and Forestry Experiment Station
College of Agriculture and Forestry
Robert H. Maxwell, Director
Morgantown

Nutrient Fluxes for Two Small Watersheds: Seven-Year Results from the West Virginia University Forest

Ray R. Hicks, Jr., Darlene Mudrick and
Edwin Townsend

Introduction

The cycling of minerals is one of the most important processes occurring in forest ecosystems. A number of recent studies have used the small watershed approach to develop a mineral nutrient budget where substance output from streamflow is subtracted from precipitation input to determine the net gain or loss of elements to the system (Bormann and Likens 1979, Henderson and others 1978, Peterson and Rolfe 1982a). A similar study of mineral cycling has been under way at the West Virginia University (WVU) Forest near Morgantown.

The data reported here document seven years of continuous study of precipitation input and stream output from two small forested watersheds at the Forest. The two watersheds, although spatially proximal, represent extremes in several attributes. One (WS1) was on a north-facing aspect with a high-quality site for tree growth that supported a yellow-poplar, red oak and white oak cover type. The other watershed (WS2) was on a southwest slope with a relatively poor growing site that supported a chestnut oak forest type. Sallese and others (1982) and Michel (1984) reported earlier results on the two watersheds suggesting that stream water from WS1 contained higher concentrations of Ca^{+2} , Mg^{+2} and K^{+} than WS2 and had a higher capacity to buffer the precipitation, which had an average pH of about 4.0. Frank (1981) conducted a comprehensive analysis of the soils of the two watersheds. His findings indicated that soils in WS1 had higher amounts of Ca^{+2} , Mg^{+2} , PO_4^{-3} and K^{+} than those of WS2. WS2 had lower soil pH and higher levels of extractable Fe and Mn. The soils of both watersheds were classified as the DeKalb series (Patton and others 1959). Since the underlying geology of the two watersheds was similar, Hicks and Frank (1984) speculated that the factors causing the observed differences in the two watersheds were biological and related to processes such as litter chemistry, litter decomposition rates and nutrient uptake.

The process of nutrient cycling has been the subject of study in many different ecosystems. For example, Henderson and others (1978) contrasted nutrient cycling in the Cascade Mountains of Oregon with that of southern Appalachian watersheds in North Carolina and eastern Tennessee. They found that bedrock composition had an important effect on cation outputs. They also discussed the important differences between hardwood ecosystems (Appalachians watersheds) and conifer ecosystems (Cascades). In spite of their differences, all three ecosystems were found to be effective in conserving and retaining elements through nutrient cycling. At the Hubbard Brook Forest in New Hampshire's White Mountains, Vitousek (1977) reported that stream element concentrations in this northern hardwood ecosystem were regulated by several processes, including precipitation chemistry, evapotranspiration, rock weathering and plant litter accumulation.

The role of atmospheric input to the nutrient cycle has been discussed by several authors. Peterson and Rolfe (1982) studied floodplain and upland forests in central Illinois and reported that the contribution of nutrients to the forest floor from throughfall was relatively small compared to input from decomposing leaf litter. However, the elemental input from precipitation and liquid throughfall are in ionic form and readily available for plant uptake. Likens and others (1976) found that precipitation chemistry was an important component of nutrient cycling in the Hubbard Brook Experimental Forest in New Hampshire. They also found that the H^+ and NO_3^- concentrations in precipitation falling on the Hubbard Brook Forest had increased 1.4-fold over a 10-year period. Atmospheric input of N was also found to have a significant impact on the nitrogen chemistry of a northeastern Tennessee stream. The magnitude of that impact was dependent upon season and other factors (Nuckols and Moore 1982). Season was also found to be important in the amounts of elements dissolved in precipitation in a Mississippi study (Lockaby 1986). In a tropical ecosystem in Venezuela, precipitation pattern was the primary factor controlling soil water chemistry (Grimm and Fassbender 1981).

The geology of an ecosystem is an important factor governing the net chemical export from watersheds. Rochelle and others (1989) found geology to be a primary factor in determining how watersheds in the northeastern United States responded to acid deposition. The geology of our study area is discussed in detail by Hare (1957). In general, the bedrock is part of the Upper Connequenesing sandstones of the Pottsville series. The soils formed from these parent materials are often stony and relatively acidic with a pH average of about 4.5.

A number of investigators have found that biological factors have an important bearing on the biogeochemistry of forested watersheds. Miller and others (1990) concluded that differences in catchment water chemistry in Great Britain were primarily due to vegetational or soil induced processes.

Litter type and decomposition rates are important factors governing stream chemistry. Dwyer and Merriam (1981) investigated the effect of topographic heterogeneity on litter decomposition. Similarly, Welbourn and others (1981) found that soil chemistry was significantly correlated with litter input. Other investigators have found that plant species composition and forest cover has an important impact on mineral cycling in forested watersheds (Peterson and Rolfe 1982; Swank and Douglass 1977; Mahendrappa 1989; Sokolov 1983; Verry and Timmons 1982).

An important function of forested ecosystems is the ability to buffer acidic deposition. Mahendrappa (1986) found that forests of certain hardwood species had a greater ability to neutralize acidic rainwater than did coniferous forests in New Brunswick, Canada. Similarly, Foster (1985) found that rainwater with a seasonal average pH of 4.4 was partially neutralized by interaction with the canopy of a Canadian maple-birch forest. Miller (1984) attributed the alteration of pH in forest canopies to the hydrogen ion exchange with base cations that occurs on leaf surfaces.

Nutrient cycling is a highly seasonal process regulated by seasonal variations in biotic processes (tree growth, physiological functioning, leaf fall) and climatic processes (temperature, precipitation, solar radiation). Peterson and Rolfe (1985) found statistically significant temporal differences in the cycling of several nutrients in a floodplain forest in central Illinois. Periods of unusual climatic events such as drought can alter the nutrient cycling response of forested watersheds. Settergren and others (1978) reported that during a period of lower-than-normal precipitation, net gain for K^+ , Na^+ and Ca^{+2} occurred in an Ozark watershed in Missouri, whereas most other studies in the eastern United States show export for these elements.

The two watersheds at the WVU Forest occur on essentially the same geologic formations and are subjected to similar precipitation (both quantitatively and qualitatively). It seems logical that the difference in response of the two watersheds is related to biological factors such as forest cover and/or leaf litter dynamics. An additional possibility is the effect of energy flux that is associated with aspect. Frank (1981) did an in-depth soil analysis of the entire area, including the two watersheds, and found that soil nutrient concentrations were associated with aspect. Higher soil values of Mn and K were associated with northeast slopes, while higher values of Fe and H were associated with southwest slopes. In another study, Sallese and others (1982) placed lysimeter tubes at 6 locations within each watershed and measured soil water chemistry during the 1981 growing season. Their results showed that all elements demonstrated seasonal changes. For Ca^{+2} and Mg^{+2} , highest values occurred during the mid-summer period with lowest values in the spring (May-June). These relationships were reversed for K^+ and Na^+ .

Generally, element concentration was higher in soil water from WS1 than from WS2, especially for K^+ and Mg^{+2} .

Peterson and Rolfe (1982a, 1982b) also found species-specific responses of watersheds from upland and bottomland forest types in central Illinois. They further concluded that the annual mineral contribution of precipitation was small compared to that from leaf litter, with the exception of potassium. Johnson and others (1985) studied the cycling of K^+ , Ca^{+2} and Mg^{+2} and compared the fluxes of elements between a chestnut oak (*Quercus prinus* L.) and a yellow-poplar (*Liriodendron tulipifera* L.) cover type in eastern Tennessee. This study bears several similarities to ours, both in the species occupying the sites and in the general response patterns, where the yellow-poplar forest exported greater amounts of cations than the chestnut oak forest. The corroboration of our previously reported results by Johnson and others provides still more motivation to seek answers about why these differences occur.

Methods

Two small watersheds were selected for study at the West Virginia University (WVU) Forest in Preston County, W.Va. One 40-acre watershed, located on a northeast-facing slope, was dominated by a yellow-poplar forest with components of northern red oak (*Quercus rubra*), black cherry (*Prunus serotina*) and red maple (*Acer rubrum*). The other, approximately 75-acre, watershed was situated on a southwest-facing aspect with chestnut oak (*Quercus prinus*) and northern red oak as principal cover species (Figure 1). WS1, on the northeast slope, possessed the best growing sites. Although they are essentially the same age, trees were noticeably larger on WS1 than on WS2.

In August 1984, a weir was constructed on WS1 using the design of Whipkey (1961). A 120° V-notch control section was established, and an event recorder was installed. The weir was rated by directly measuring the amounts of water produced over a given time interval at different stages of water over the weir (Michel 1984). In addition to flow measurements from the weir, water samples were collected weekly at three stations beginning in October 1983, before the weir was constructed. One of these collections was taken using a precipitation sampler and one each from the streams flowing from WS1 and WS2. These weekly collections were taken to a laboratory and analyzed for Ca^{+2} , K^+ , Mg^{+2} , Na^+ , PO_4^{-3} , NO_3^- and SO_4^{-2} . Not all elements were measured in all years. The data for streamflow were processed at the Northeast Forest Experiment Station Laboratory, USDA Forest Service, in Parsons, W.Va., to produce total streamflow per day and per month. Streamflow for WS2, which was not equipped with a weir, was predicted using a regression procedure and monthly precipitation to find

monthly streamflow (Nik 1981). We used the same technique to estimate streamflow for WS1 for months that were missing streamflow data due to equipment failure or other reasons.

The element concentrations (milligrams per liter) were averaged per month and then multiplied by the number of liters flowing from the watershed per month to obtain monthly nutrient export. We multiplied the monthly rainwater volume (obtained from the nearby Coopers Rock weather station) by the average concentration of elements in the water to obtain monthly nutrient import.

Results

In our watersheds, outputs exceeded inputs for Ca^{+2} and Mg^{+2} (Table 1, Figure 2); thus, when expressed as an annual nutrient budget (input minus output) they were negative. Our results for NO_3^- are corroborated by results from the northern hardwoods (Bormann and Likens 1979). Negative budgets are typical for substances other than NO_3^- studied in forested watersheds in the eastern United States (Johnson and Swank 1973). One way of comparing the mean input/output data is by examining the proportion that output (from streamflow) is of input from precipitation. The substances monitored were ranked in this regard as follows: NO_3^- (170%), PO_4^{3-} (150%), Na^+ (93%), K^+ (92%), Ca^{+2} (52%) and Mg^{+2} (12%). For substances such as Mg^{+2} and Ca^{+2} , where input is less than output, the additional output probably came from internal sources within the watershed, such as rock weathering.

An interesting finding is the seasonal distribution of inputs and outputs. In Table 1, it can be seen that substance inputs from precipitation generally displayed little or no seasonal pattern. Peak outputs for all substances occurred in the months of November through March (Figures 3–10). In part, this can be explained by the higher streamflows that occurred during this period (Figure 11). Certainly the low exports that occurred in August and September can be attributed to low streamflow during these months. The physiological activity of plants growing in the watersheds has an important influence on these relationships as well. Trees are generally dormant from October through April, and increased substance output during that period may reflect the lack of plant uptake during the dormant season. Certain substances (Na^+ , K^+ and PO_4^{3-}) showed a lower tendency to be seasonally cyclical than others (Ca^{+2} , Mg^{+2} and NO_3^-). For Na^+ , the explanation probably lies in the fact that it is not an element required in plant physiological processes. Na^+ is not selectively taken up or stored in plant tissues. It would be less subject to the effects of plant uptake than required elements. For K^+ and PO_4^{3-} , the situation is not as clear. The peak export of K apparently occurs in November for both watersheds. This might be a function of release of K^+ from leaf litter associated with decomposition of, and

leaching from, recently fallen leaves. Ca^{+2} , Mg^{+2} and nitrate cycles generally follow patterns associated with the hydrologic and physiological dynamics of the forest system. One factor that seems to drive the nutrient input/output process is the annual hydrologic cycle. There was a slight seasonal pattern observed for precipitation volume with the highest monthly precipitation occurring during the spring/summer season and the lowest through the winter (Figure 11). The variation in precipitation was relatively small, however, compared to that of streamflow. The streamflow was lowest during the summer season, reflecting the transpirational impact of the forest on streamflow. Conversely, the highest flows occurred during the winter months when trees were dormant. The monthly mean outputs from the watersheds reflect the differences in streamflow volume for most elements (Tables 2-7). This effect can also be seen in Figures 3-10. The seasonal volume effect may be partially offset by increased concentration of certain elements (e.g., sodium) during the low flow periods of late summer.

Typically, for all substances, the output from WS1 exceeded that of WS2 (Table 1-7, Figures 3-8). This is consistent with the results of Johnson and others (1985). They found that a yellow-poplar ecosystem produced higher outputs of substances than a chestnut oak forest, which is analogous to our watersheds 1 and 2. These results are also consistent with earlier reports from watersheds 1 and 2 (Sallese and others 1982).

Tables 2-7 illustrate the seasonal and year-to-year fluctuations in nutrient inputs and outputs. Although the annual sums seem to indicate yearly variability in substance export, these results should be viewed with caution since three different chemistry labs conducted the analyses over the years. Although they all stated that EPA standard tests were used, noticeable and consistent changes always seemed to accompany changes in labs.

The differential pH response of the two watersheds is another aspect that deserves attention. The precipitation falling on our watersheds was generally acidic, with an average pH of approximately 3.9 (Figure 12). There was little noticeable seasonal trend to precipitation pH, although the highest average monthly value (4.3) was for the month of January and the lowest monthly value (3.6) was for June. There was little correlation between the streamwater pH and that of precipitation. The Pearson correlation coefficients for WS1 and WS2 were 0.14 and 0.18, respectively. The mean annual stream water pH for WS1 was approximately 5.1, compared to an annual average of 4.4 for WS2. Thus precipitation contains a concentration of H^{+} that is about 3.75 times greater than streamwater from WS2 and 18.75 times greater than in WS1. Both WS1 and WS2 did demonstrate a seasonal pH response, although it seemed more prominent in WS1 (Figure 12). Highest pH levels in both watersheds occurred during the spring and summer months. There was a high correlation between the monthly pH values of WS1 and WS2 ($r = 0.90$).

Discussion and Conclusions

After seven years of study on two small watersheds at the WVU Forest, certain conclusions are becoming clear. First, the nutrient input/output budgets for calcium and magnesium are negative, indicating that our watersheds are exporting more of these substances than they are importing from precipitation. This is consistent with the findings of other studies in the eastern United States. We found that nitrate and phosphate had positive budgets and sodium and potassium were about balanced. We found a pronounced seasonal output response, more so for some elements than for others. In great measure, this reflects the seasonal hydrologic pattern of the watersheds rather than precipitation volume or chemistry, although some of the seasonality may be related to cyclical biological phenomena and/or the proportion of ground water to surface water present in streams at a given time.

We found WS1 was consistently higher in its output of elements compared to WS2. This seems to relate to the difference in vegetative cover on the two watersheds rather than to geologic or climatic phenomena. Perhaps the leaf litter produced by the species growing on WS1 was more readily decomposed, allowing more nutrient exportation from that site than from WS2.

Average precipitation pH was very low (3.9 annual average), and streamwater from WS1 had a much higher pH than that from WS2. In general, the pH of streamwater in WS1 was a whole unit higher than that of the incoming precipitation, whereas streamflow from WS2 was only slightly higher than the precipitation pH.

A major conclusion of this work is that the forest exerts a strong influence on the biogeochemistry of the watersheds. For example, the seasonal nature of substance output can, in large measure, be explained by the seasonal cycle in stream hydrology, which in turn is related to the effect of transpiration on streamflow. The consistent differences in nutrient output and pH between WS1 and WS2 are most logically explained by the difference in vegetative cover (yellow-poplar, maple, cherry on WS1 versus oaks on WS2).

It appears that the good growing conditions on WS1 are conducive to more rapid nutrient cycling and even, perhaps, to greater nutrient output. Hicks and Frank (1984) found that soils on the north and northeast aspects contained higher levels of several essential elements than did soils on the south and southwest aspects. This, in combination with the input/output data reported here, suggests that mineral nutrients are more abundant and more rapidly cycled on the better growing sites than on the poor ones.

The hydrologic and nutrient cycling results reported here have significance in their own right, but these data may also serve as a baseline for

future studies. For example, the effect of disturbances such as gypsy moth defoliation and timber harvesting on nutrient cycling and hydrology might be compared to these data that represent a relatively undisturbed condition.

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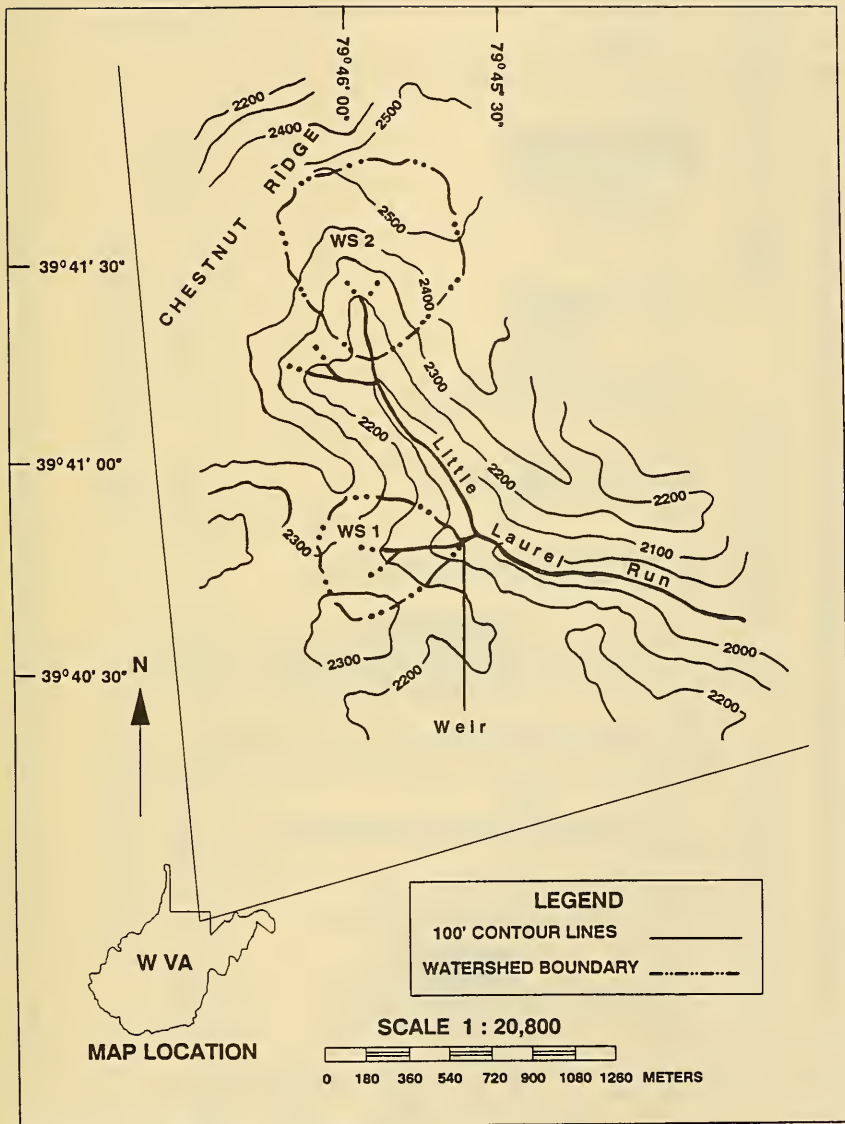


Figure 1. Location of study watersheds at the West Virginia University Forest.

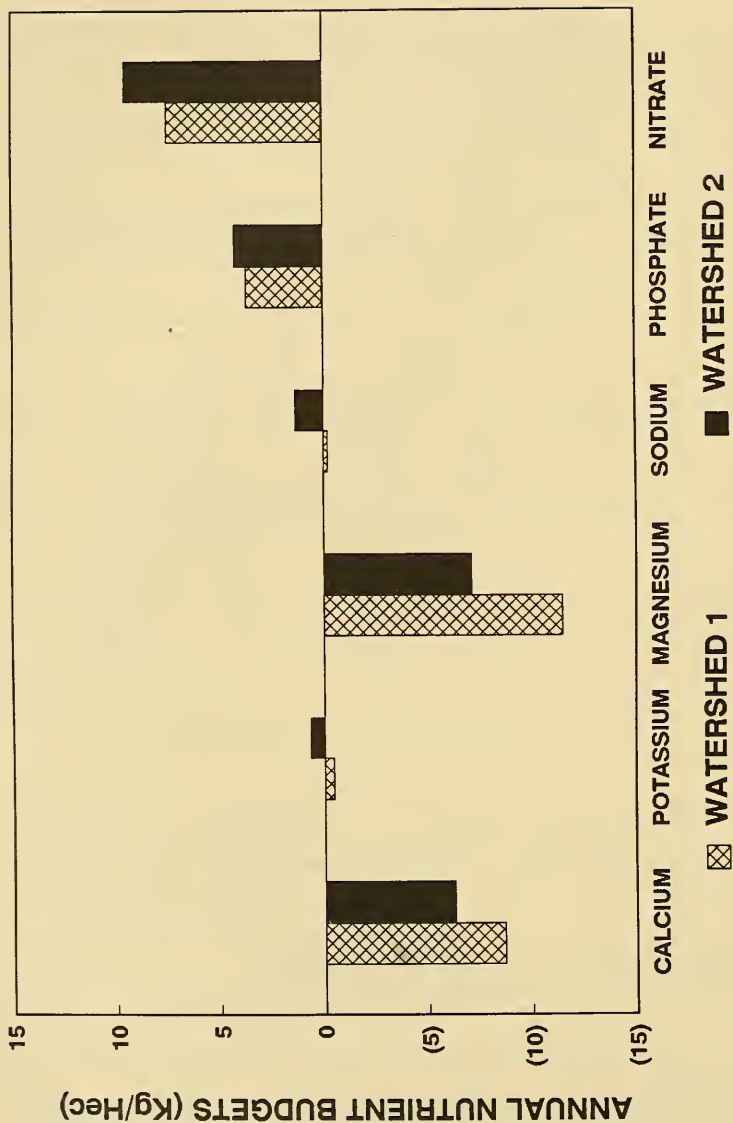


Figure 2. Average yearly nutrient budgets (inputs minus outputs) for 6 substances studied.

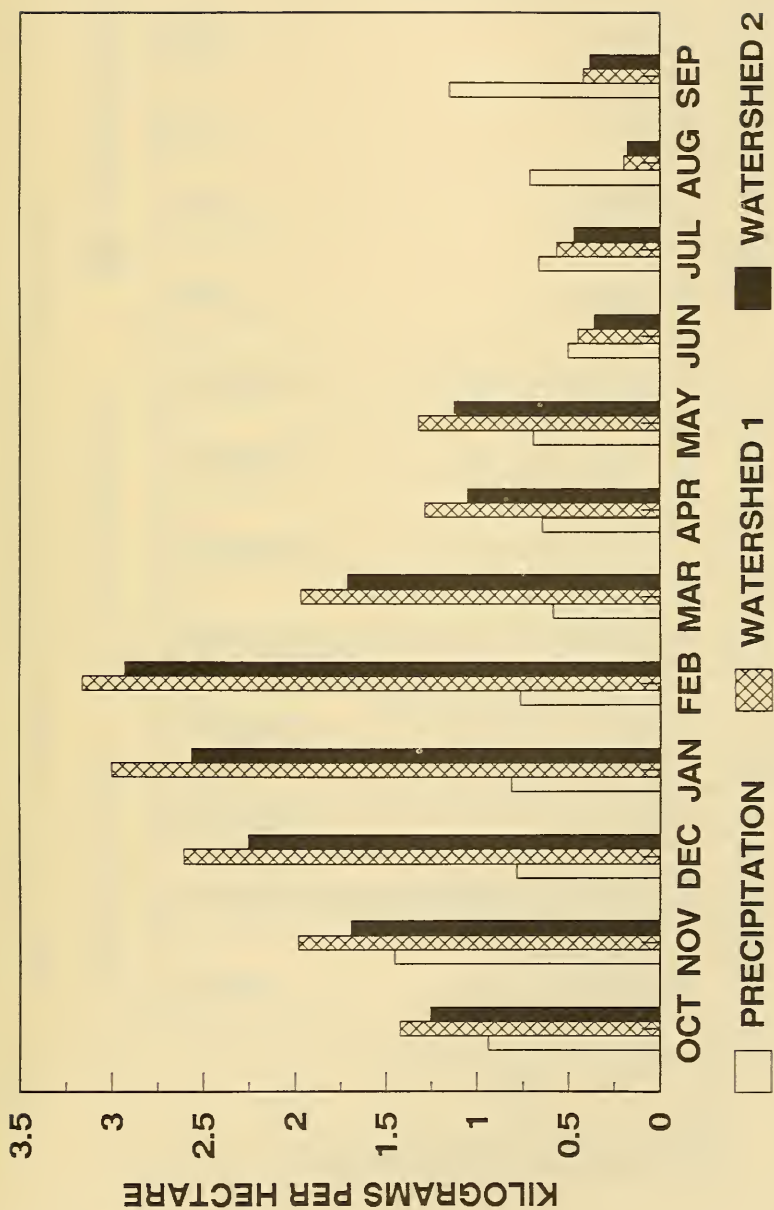


Figure 3. Monthly calcium inputs and outputs from watersheds 1 and 2.

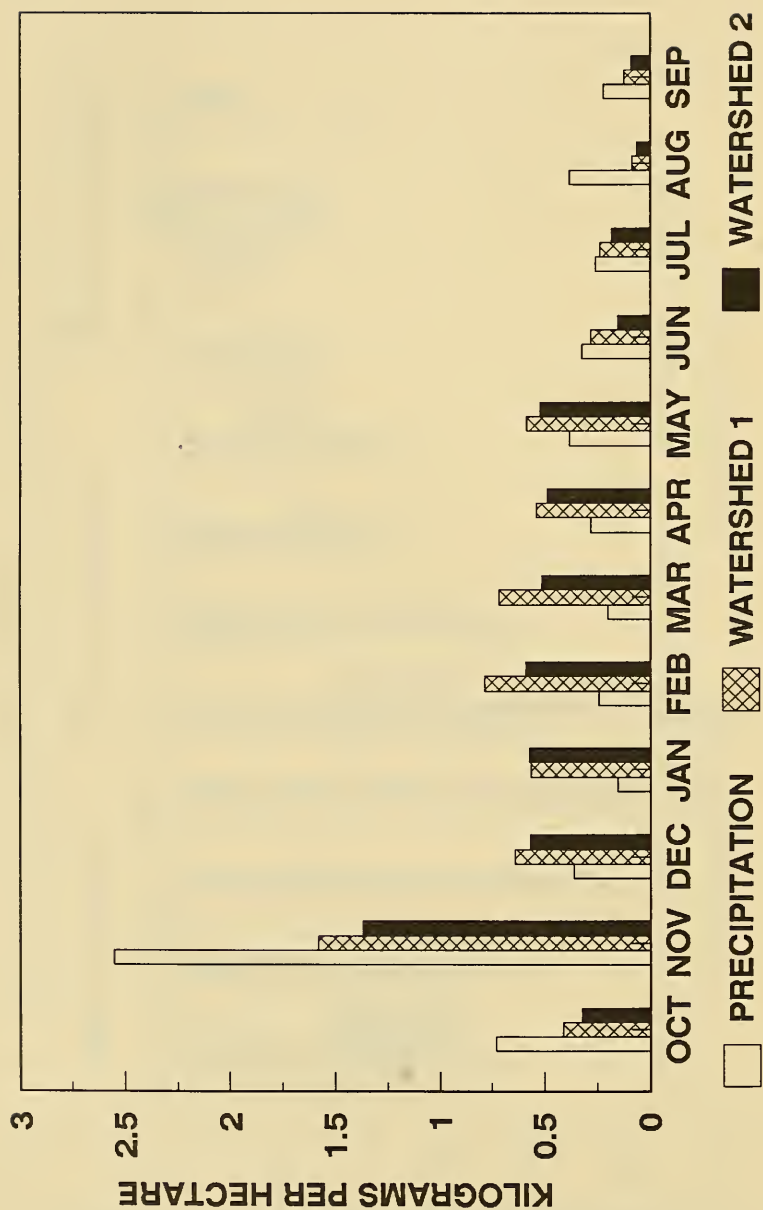


Figure 4. Monthly potassium inputs and outputs from watersheds 1 and 2.

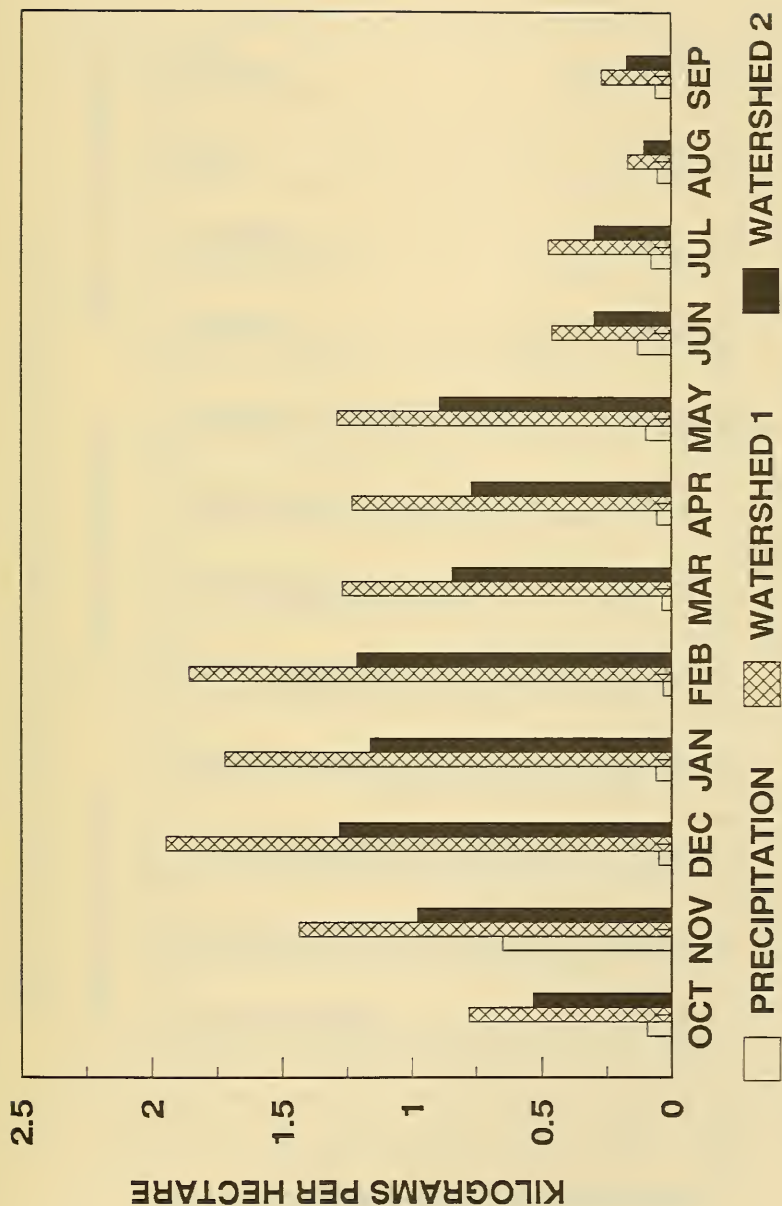


Figure 5. Monthly magnesium inputs and outputs from watersheds 1 and 2.

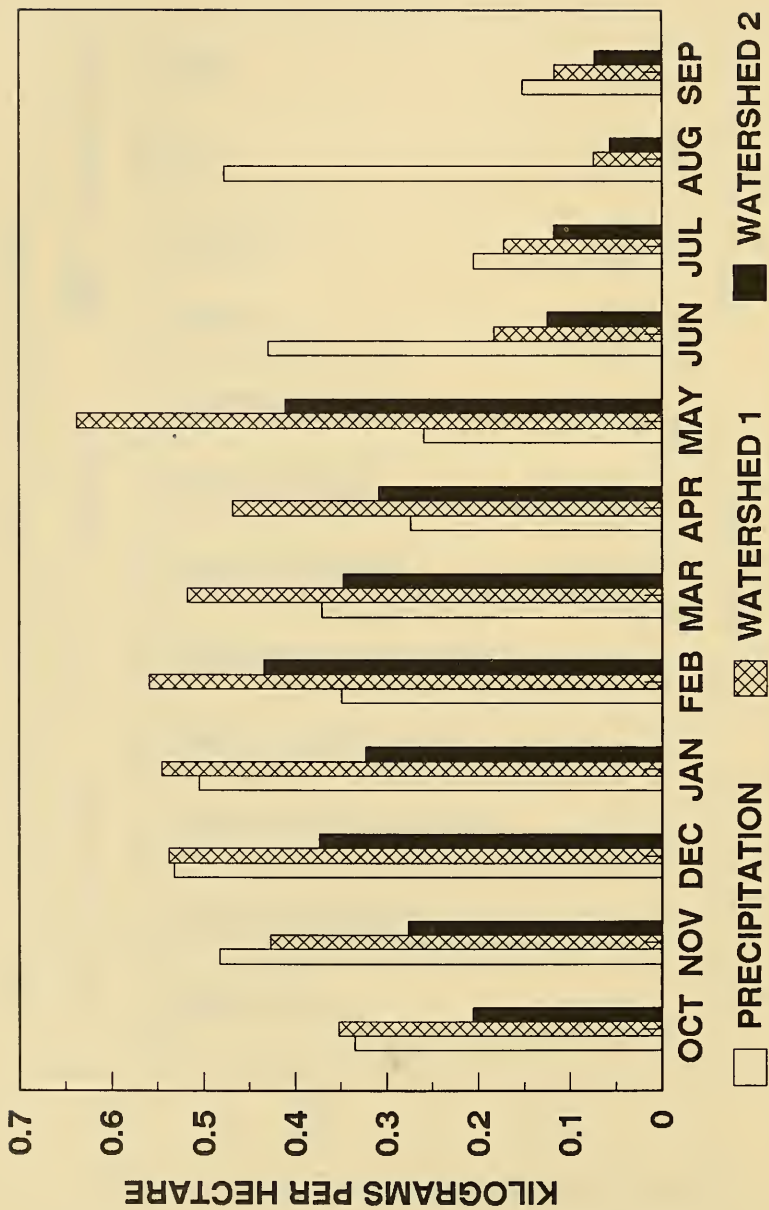


Figure 6. Monthly sodium inputs and outputs from watersheds 1 and 2.

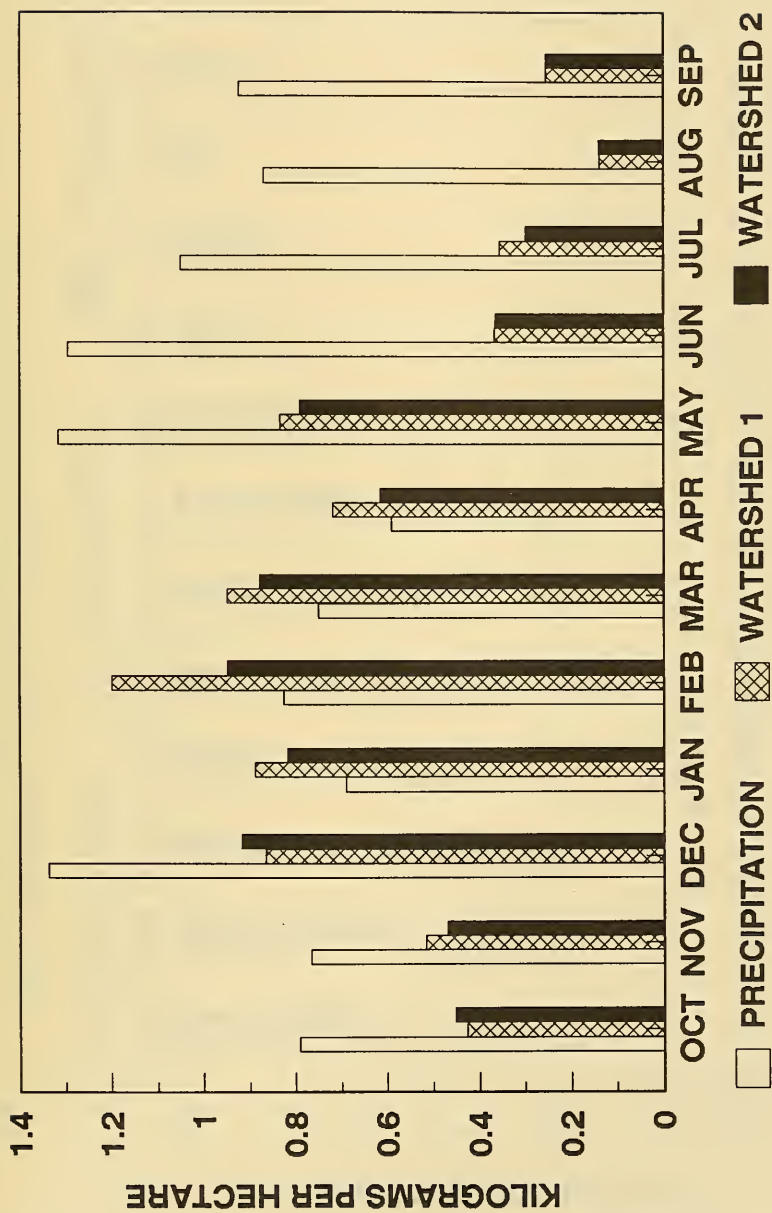


Figure 7. Monthly phosphate inputs and outputs from watersheds 1 and 2.

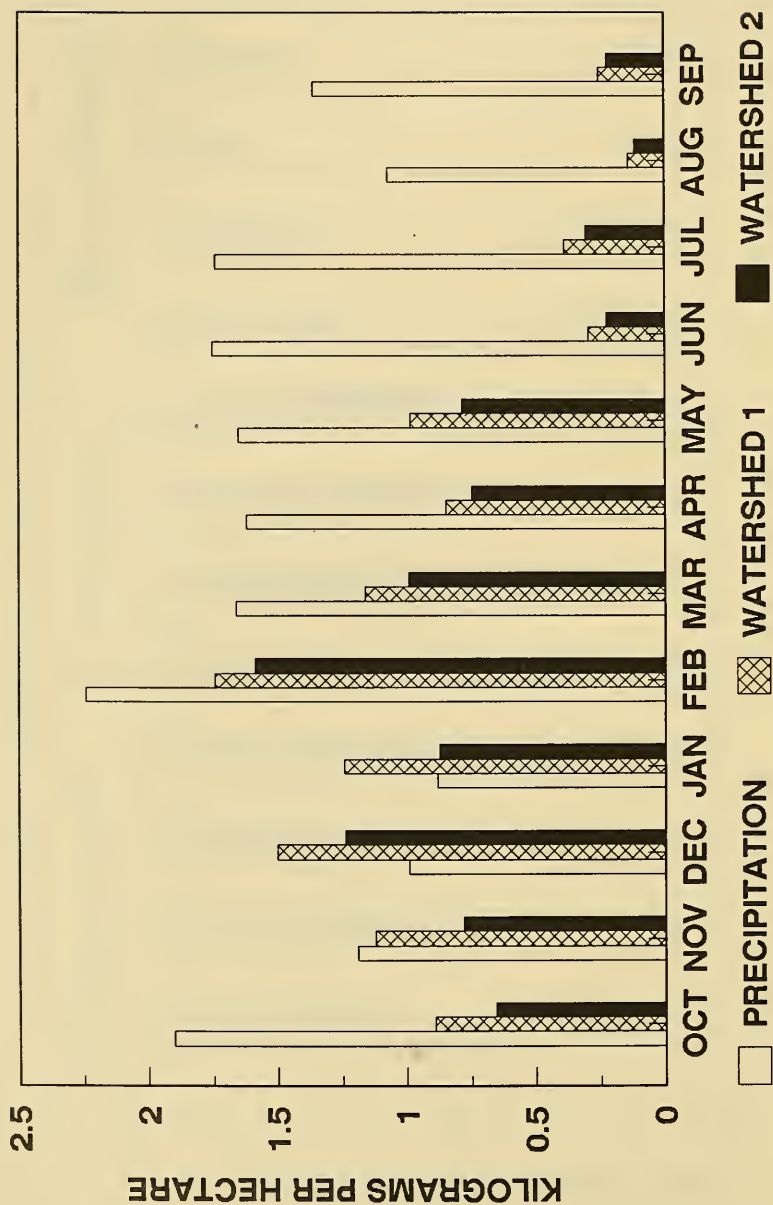


Figure 8. Monthly nitrate inputs and outputs from Watersheds 1 and 2.

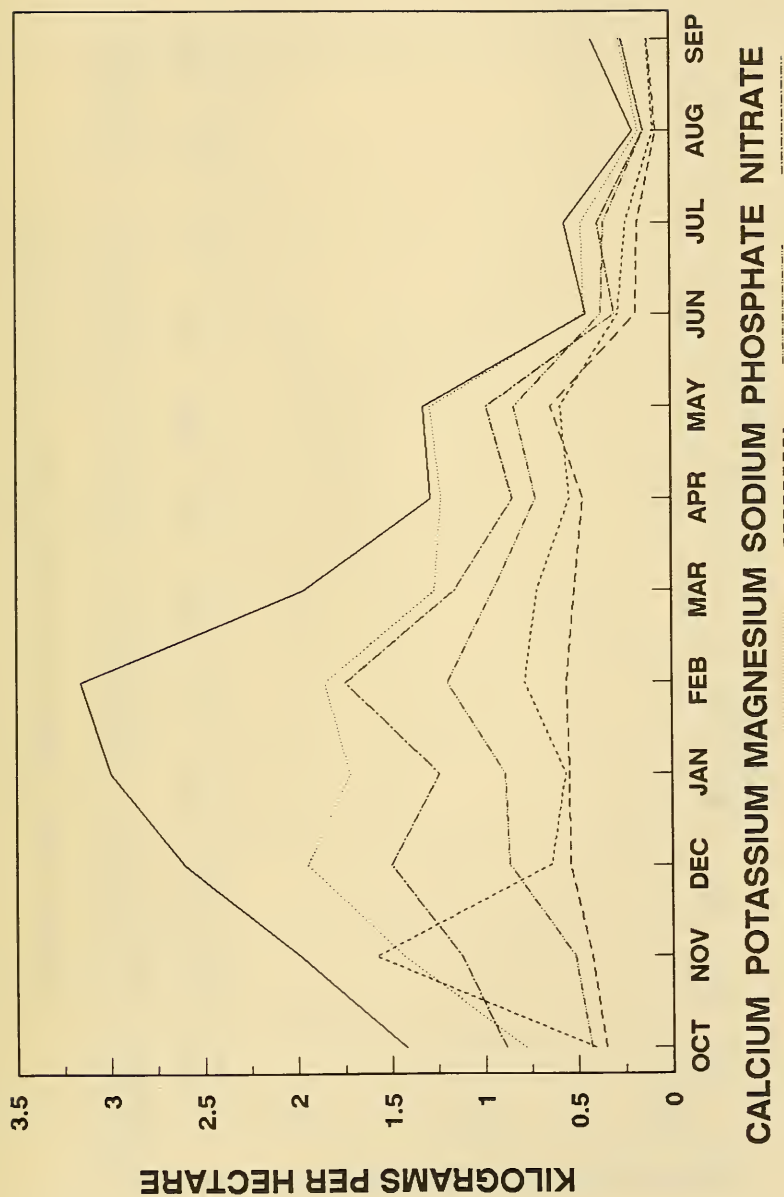


Figure 9. Mean monthly output of elements (kg/ha) from watershed 1.

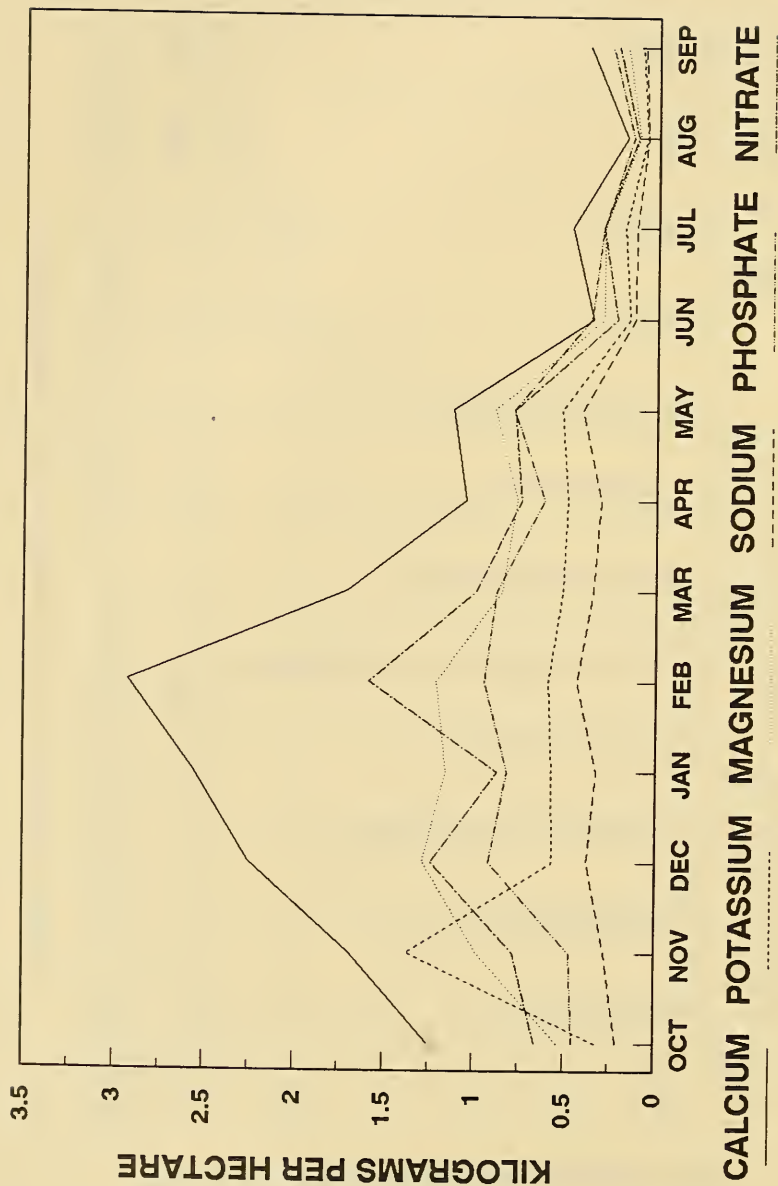


Figure 10. Mean monthly output of elements (kg/ha) from watershed 2.

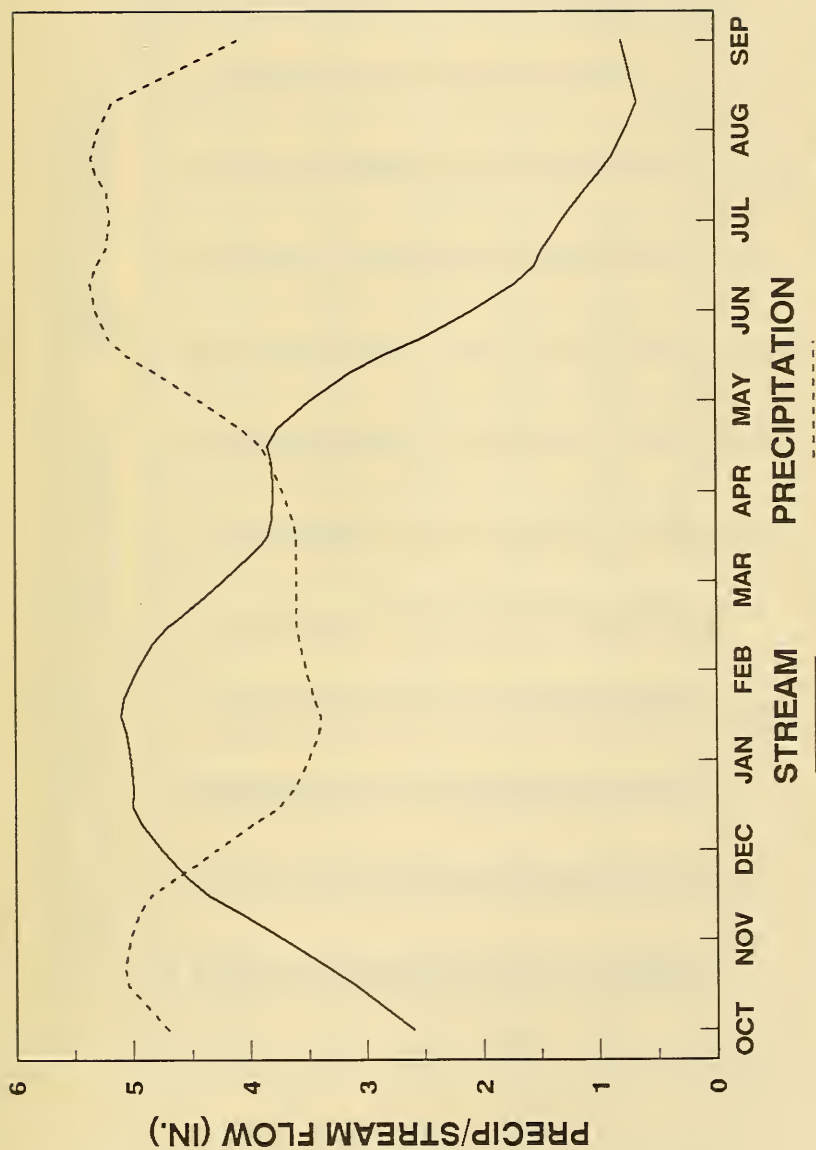


Figure 11. Hydrologic data for precipitation and watersheds 1 and 2 over the study period.

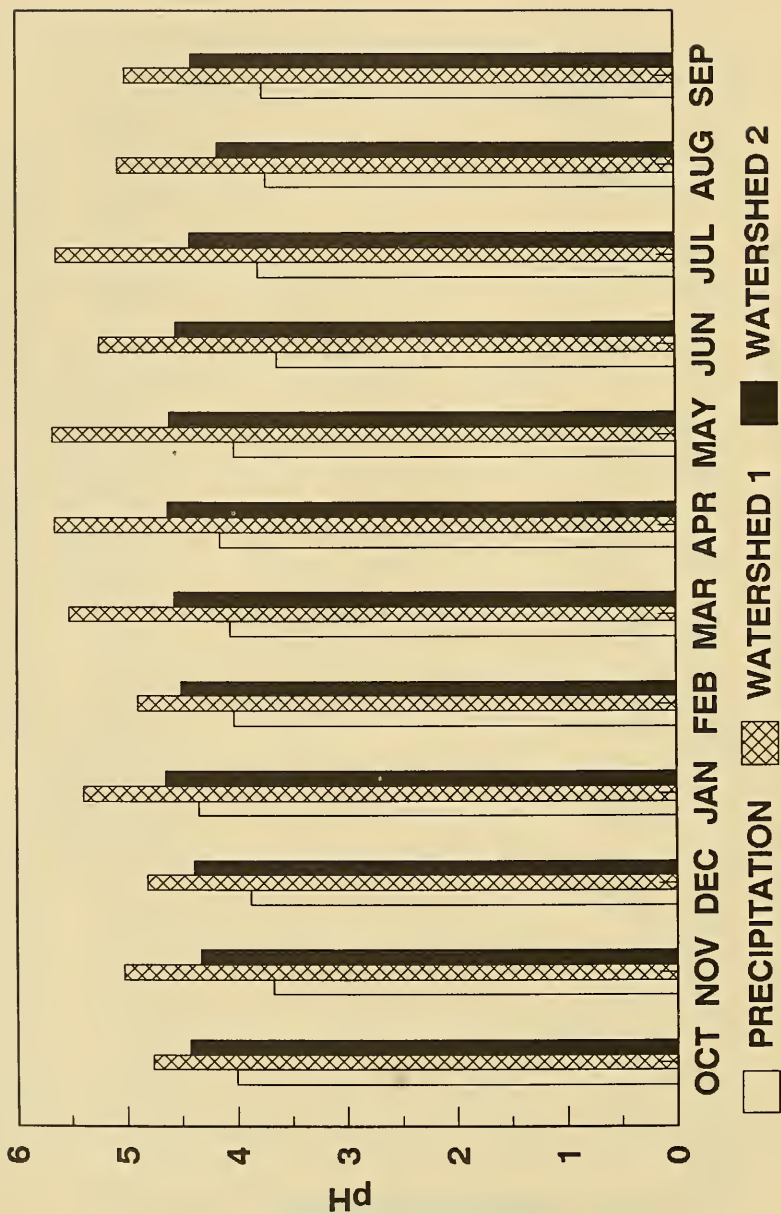


Figure 12. Monthly averages for pH for precipitation and watersheds 1 and 2.

Table 1. Mean Monthly Precipitation Input and Output of Elements in Kilograms per Hectare on Watershed 1 and Watershed 2. (Data from October 25, 1983 to February 28, 1991.)

	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	ANNUAL BUDGET SUMS	I-O
CALCIUM														
Input C1	0.9400	1.4500	0.7800	0.8100	0.7600	0.5800	0.6400	0.6900	0.5000	0.6600	0.7100	1.1500	9.6700	-8.6821
Output WS1	1.4230	1.9806	2.6027	2.9949	3.1584	1.9660	1.2857	1.3212	0.4464	0.5635	0.1949	0.4148	18.3521	-6.2765
Output WS2	1.2550	1.6926	2.2516	2.5576	2.9251	1.7079	1.0525	1.1250	0.3545	0.4714	0.1746	0.3787	15.9465	
POTASSIUM														
Input C1	0.7300	2.5500	0.3600	0.1500	0.2400	0.2000	0.2800	0.3800	0.3200	0.2600	0.3800	0.2200	6.0700	-0.4660
Output WS1	0.4100	1.5800	0.6400	0.5631	0.7845	0.7165	0.5406	0.5853	0.2771	0.2356	0.0830	0.1203	6.5360	+0.6437
Output WS2	0.3200	1.3700	0.5686	0.5716	0.5909	0.5126	0.4857	0.5230	0.1505	0.1826	0.0642	0.0866	5.4263	
MAGNESIUM														
Input C1	0.0943	0.6500	0.0514	0.0600	0.0333	0.0357	0.0557	0.0986	0.1300	0.0771	0.0543	0.0600	1.4004	-11.4745
Output WS1	0.7811	1.4344	1.9433	1.7186	1.8545	1.2668	1.2287	1.2858	0.4580	0.4701	0.1666	0.2670	12.8749	-7.1337
Output WS2	0.5316	0.9790	1.2800	1.1591	1.2109	0.8462	0.7708	0.8922	0.2951	0.2949	0.1040	0.1703	8.5341	
SODIUM														
Input C1	0.3349	0.4817	0.5320	0.5047	0.3495	0.3707	0.2739	0.2586	0.4291	0.2047	0.4773	0.1519	4.3710	-0.2152
Output WS1	0.3522	0.4264	0.5375	0.5456	0.5589	0.5168	0.4675	0.6373	0.1820	0.1717	0.0736	0.1167	4.5862	+1.3220
Output WS2	0.2053	0.2764	0.3738	0.3235	0.4336	0.3470	0.3081	0.4107	0.1239	0.1177	0.0562	0.0728	3.0490	
PHOSPHATE														
Input C1	0.7910	0.7650	1.3350	0.6900	0.8260	0.7500	0.5920	1.3140	1.2940	1.0480	0.8683	0.9233	11.1966	+3.6907
Output WS1	0.4270	0.5161	0.8642	0.8873	1.1984	0.9487	0.7190	0.8328	0.3668	0.3547	0.1371	0.2538	7.5059	+4.2503
Output WS2	0.4506	0.4695	0.9169	0.8179	0.9489	0.8780	0.6165	0.7914	0.3649	0.2989	0.1383	0.2545	6.9463	
NITRATE														
Input C1	1.9000	1.1900	0.9900	0.8800	2.2400	1.6600	1.6200	1.6500	1.7500	1.7400	1.0700	1.3600	18.0500	+7.4888
Output WS1	0.8895	1.1210	1.5000	1.2435	1.7438	1.1607	0.8462	0.9831	0.2935	0.3870	0.1392	0.2537	10.5612	+9.5337
Output WS2	0.6563	0.7800	1.2400	0.8718	1.5861	0.9916	0.7467	0.7841	0.2237	0.3025	0.1127	0.2208	8.5163	

Table 2. Monthly Means and Annual Sums (kg/ha) for Calcium.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	0.230	.	1.370	0.150	2.580	0.390	0.120	0.81
Output WS1	2.557	.	2.960	1.211	5.322	3.905	2.014	2.99
Output WS2	1.934	.	2.292	0.936	5.162	3.287	1.735	2.56
FEBRUARY								
Input C1	0.320	.	0.410	0.070	3.600	0.140	0.050	0.76
Output WS1	3.014	2.253	3.949	0.864	4.745	5.063	2.221	3.16
Output WS2	2.584	.	4.204	0.708	4.459	3.703	1.891	2.92
MARCH								
Input C1	0.320	0.400	0.220	0.350	2.470	0.210	0.060	0.58
Output WS1	2.105	1.814	1.604	0.703	4.059	2.478	0.999	1.97
Output WS2	1.621	1.345	1.568	0.578	3.834	2.145	0.865	1.71
APRIL								
Input C1	1.380	0.290	1.410	.	0.490	0.130	0.110	0.64
Output WS1	2.022	1.141	1.410	0.773	0.972	1.063	1.619	1.29
Output WS2	1.397	0.837	1.314	0.555	0.919	0.914	1.431	1.05
MAY								
Input C1	0.990	1.310	0.640	0.130	1.270	0.130	0.200	0.69
Output WS1	2.028	1.005	0.558	0.416	1.264	1.972	2.006	1.32
Output WS2	1.451	0.727	0.469	0.448	1.244	1.732	1.802	1.12
JUNE								
Input C1	0.270	0.860	1.090	0.070	0.870	0.150	0.170	0.50
Output WS1	0.026	0.812	0.223	0.388	0.000	1.206	0.470	0.45
Output WS2	0.020	0.625	0.157	0.303	0.000	0.987	0.389	0.35
JULY								
Input C1	0.230	0.750	0.910	0.550	1.800	0.200	0.160	0.66
Output WS1	0.725	0.674	1.024	0.012	0.349	0.700	0.459	0.56
Output WS2	0.521	0.535	0.909	0.011	0.354	0.581	0.388	0.47
AUGUST								
Input C1	0.170	0.230	0.720	1.460	1.980	0.200	0.220	0.71
Output WS1	0.393	0.036	0.067	0.289	0.342	0.098	0.139	0.19
Output WS2	0.265	0.029	0.058	0.294	0.394	0.079	0.103	0.17
SEPTEMBER								
Input C1	0.330	0.190	0.510	4.370	2.150	0.200	0.280	1.15
Output WS1	0.063	0.008	0.082	0.397	0.476	0.225	1.652	0.41
Output WS2	0.044	0.006	0.064	0.369	0.479	0.181	1.508	0.38
OCTOBER								
Input C1	0.740	0.350	1.420	2.470	1.250	0.460	0.240	0.94
Output WS1	1.252	0.099	1.027	2.640	1.186	1.089	2.283	1.37
Output WS2	0.850	0.079	1.035	2.490	1.160	0.959	1.939	1.22
NOVEMBER								
Input C1	0.370	4.870	0.110	3.730	0.590	0.210	0.240	1.45
Output WS1	1.248	2.129	1.589	4.177	2.120	1.013	1.587	1.98
Output WS2	0.962	1.597	1.350	3.968	1.761	0.804	1.468	1.70
DECEMBER								
Input C1	0.170	0.320	0.190	3.780	0.480	0.130	0.420	0.78
Output WS1	2.022	2.008	0.935	3.112	2.682	0.963	6.497	2.60
Output WS2	1.535	1.802	0.813	2.875	2.452	0.830	5.454	2.60
ANNUAL SUMS								
Input C1	5.520	.	9.120	.	19.510	2.560	2.270	9.67
Output WS1	17.456	.	15.428	14.983	23.517	19.775	21.946	18.29
Output WS2	13.185	.	14.234	13.536	22.220	16.202	18.973	16.25

Table 3. Monthly Means and Annual Sums (kg/ha) for Potassium.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	0.020	.	0.050	0.180	0.300	0.040	0.310	0.15
Output WS1	0.837	.	0.178	0.648	0.431	0.667	0.618	0.56
Output WS2	1.003	.	0.338	0.452	0.427	0.570	0.640	0.57
FEBRUARY								
Input C1	0.030	.	0.330	0.020	0.920	0.080	0.080	0.24
Output WS1	1.449	1.211	0.407	0.315	0.454	0.848	0.808	0.78
Output WS2	0.936	.	0.449	0.266	0.411	0.768	0.714	0.59
MARCH								
Input C1	0.030	0.020	0.100	0.070	0.520	0.630	0.020	0.20
Output WS1	1.359	1.032	0.408	0.291	0.393	1.190	0.341	0.72
Output WS2	0.666	0.568	0.375	0.272	0.372	1.018	0.318	0.51
APRIL								
Input C1	0.120	0.460	0.460	0.190	0.550	0.140	0.040	0.28
Output WS1	0.731	0.492	0.690	0.477	0.309	0.481	0.606	0.54
Output WS2	0.713	0.427	0.476	0.462	0.264	0.447	0.612	0.48
MAY								
Input C1	0.550	0.530	0.320	0.350	0.460	0.260	0.220	0.38
Output WS1	0.783	0.398	0.201	0.419	0.461	0.909	0.927	0.58
Output WS2	0.758	0.329	0.156	0.326	0.399	0.873	0.820	0.52
JUNE								
Input C1	0.100	0.190	0.700	0.180	0.450	0.420	0.240	0.32
Output WS1	0.014	0.332	0.043	0.224	0.000	1.109	0.218	0.28
Output WS2	0.011	0.297	0.036	0.127	0.000	0.442	0.140	0.15
JULY								
Input C1	0.070	0.230	0.290	0.220	0.310	0.390	0.300	0.26
Output WS1	0.315	0.275	0.297	0.004	0.184	0.345	0.229	0.24
Output WS2	0.223	0.229	0.247	0.002	0.126	0.283	0.168	0.18
AUGUST								
Input C1	0.290	0.340	0.800	0.160	0.330	0.450	0.310	0.38
Output WS1	0.154	0.011	0.017	0.113	0.187	0.046	0.052	0.08
Output WS2	0.108	0.007	0.019	0.096	0.150	0.028	0.040	0.06
SEPTEMBER								
Input C1	0.230	0.080	0.270	0.210	0.010	0.580	0.140	0.22
Output WS1	0.026	0.002	0.033	0.121	0.122	0.104	0.435	0.12
Output WS2	0.022	0.001	0.029	0.074	0.063	0.070	0.347	0.09
OCTOBER								
Input C1	0.540	0.070	0.450	1.120	0.600	0.930	1.420	0.73
Output WS1	0.500	0.017	0.251	0.821	0.230	0.323	0.698	0.41
Output WS2	0.457	0.019	0.203	0.258	0.196	0.532	0.610	0.32
NOVEMBER								
Input C1	0.180	0.730	6.610	7.500	0.170	1.890	0.790	2.55
Output WS1	0.529	0.319	7.952	1.261	0.363	0.340	0.307	1.58
Output WS2	0.409	0.328	7.419	0.531	0.333	0.306	0.283	1.37
DECEMBER								
Input C1	0.060	0.020	0.080	1.220	0.330	0.600	0.220	0.36
Output WS1	0.861	0.478	0.640	0.288	0.509	0.295	1.409	0.64
Output WS2	0.742	0.402	0.527	0.239	0.425	0.276	1.369	0.57
ANNUAL SUMS								
Input C1	2.220	.	10.460	11.430	4.950	6.400	4.100	6.07
Output WS1	7.557	.	11.117	4.982	3.644	6.657	6.647	6.53
Output WS2	6.049	.	10.274	3.106	3.167	5.615	6.061	4.93

Table 4. Monthly Means and Annual Sums (kg/ha) for Magnesium.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	0.020	.	0.110	0.050	0.180	0.000	0.030	0.060
Output WS1	1.715	.	1.716	2.299	2.113	1.360	1.109	1.720
Output WS2	1.192	.	1.624	1.349	1.295	0.767	0.727	1.160
FEBRUARY								
Input C1	0.040	.	0.070	0.000	0.030	0.050	0.010	0.330
Output WS1	2.051	1.645	1.979	2.365	1.932	1.866	1.142	1.854
Output WS2	1.434	.	1.411	1.388	1.164	1.107	0.761	1.211
MARCH								
Input C1	0.030	0.040	0.030	0.090	0.040	0.010	0.010	0.040
Output WS1	1.490	1.247	1.020	1.473	1.660	1.438	0.540	1.267
Output WS2	1.049	0.924	0.790	0.896	1.010	0.898	0.356	0.846
APRIL								
Input C1	0.100	0.030	0.240	0.000	0.000	0.010	0.010	0.060
Output WS1	1.638	0.939	0.879	2.232	1.362	0.673	0.877	1.229
Output WS2	1.055	0.572	0.611	1.263	0.834	0.450	0.612	0.771
MAY								
Input C1	0.130	0.170	0.130	0.130	0.030	0.030	0.070	0.100
Output WS1	1.695	0.823	0.309	1.728	1.638	1.295	1.512	1.286
Output WS2	1.110	0.531	0.214	1.104	1.004	0.863	1.418	0.892
JUNE								
Input C1	0.040	0.130	0.240	0.050	0.330	0.030	0.080	0.130
Output WS1	0.025	0.649	0.115	1.048	0.000	0.790	0.579	0.458
Output WS2	0.016	0.468	0.078	0.652	0.000	0.510	0.342	0.295
JULY								
Input C1	0.030	0.150	0.170	0.050	0.000	0.060	0.080	0.080
Output WS1	0.647	0.568	0.743	0.014	0.292	0.458	0.569	0.470
Output WS2	0.416	0.402	0.488	0.008	0.079	0.307	0.364	0.295
AUGUST								
Input C1	0.060	0.070	0.130	0.000	0.000	0.070	0.050	0.050
Output WS1	0.342	0.025	0.036	0.309	0.252	0.064	0.138	0.167
Output WS2	0.219	0.019	0.025	0.182	0.151	0.044	0.089	0.104
SEPTEMBER								
Input C1	0.050	0.090	0.090	0.070	0.040	0.040	0.040	0.060
Output WS1	0.052	0.008	0.037	0.176	0.288	0.143	1.166	0.267
Output WS2	0.034	0.005	0.024	0.105	0.162	0.095	0.766	0.170
OCTOBER								
Input C1	0.130	0.110	0.220	0.050	0.020	0.060	0.070	0.090
Output WS1	1.005	0.059	0.444	1.145	0.739	0.689	1.387	0.781
Output WS2	0.660	0.041	0.408	0.769	0.469	0.455	0.919	0.532
NOVEMBER								
Input C1	0.070	3.060	0.590	0.100	0.010	0.050	0.040	0.650
Output WS1	1.134	1.065	3.734	1.760	0.787	0.648	0.913	1.434
Output WS2	0.745	0.754	2.621	1.265	0.463	0.372	0.633	0.979
DECEMBER								
Input C1	0.020	0.010	0.090	0.030	0.080	0.030	0.100	0.051
Output WS1	2.097	1.639	2.881	1.301	1.054	0.582	4.049	1.943
Output WS2	1.268	1.205	1.798	0.826	0.785	0.407	2.671	1.280
ANNUAL SUMS								
Input C1	0.720	.	2.110	0.610	0.750	0.430	0.580	1.400
Output WS1	13.890	.	13.893	15.851	12.119	10.005	13.982	12.880
Output WS2	9.196	.	10.093	9.806	7.417	6.275	9.658	8.690

Table 5. Monthly Means and Annual Sums (kg/ha) for Sodium.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	0.0010	.	0.3660	1.3850	1.0580	0.0490	0.1690	0.505
Output WS1	0.2492	.	0.3248	0.7521	0.5979	0.5963	0.7532	0.546
Output WS2	0.1983	.	0.1585	0.3304	0.4784	0.3422	0.4333	0.324
FEBRUARY								
Input C1	0.0010	.	0.1880	0.1170	1.5490	0.1560	0.0860	0.350
Output WS1	0.2985	0.2987	0.2662	0.8099	0.4985	0.8942	0.8465	0.559
Output WS2	0.2903	.	0.2130	0.7590	0.3023	0.5554	0.4815	0.434
MARCH								
Input C1	0.0010	0.0010	0.0750	0.0920	1.3870	0.9990	0.0540	0.373
Output WS1	0.3253	0.2571	0.2211	0.3065	0.4132	1.6622	0.4327	0.517
Output WS2	0.2832	0.2353	0.2146	0.2333	0.1588	1.0445	0.2591	0.347
APRIL								
Input C1	0.0640	0.0230	0.4180	0.1710	0.9160	0.2050	0.1200	0.274
Output WS1	0.2906	0.1908	0.3126	0.4072	0.4108	0.8760	0.7848	0.468
Output WS2	0.2429	0.1497	0.2771	0.3027	0.2156	0.5114	0.4573	0.308
MAY								
Input C1	0.1130	0.1000	0.3000	0.2810	0.3340	0.2740	0.4080	0.259
Output WS1	0.3211	0.1804	0.2231	0.3293	0.5007	1.8544	1.0522	0.637
Output WS2	0.2765	0.1375	0.1380	0.2304	0.2810	1.2068	0.6050	0.411
JUNE								
Input C1	0.0300	0.0630	1.7030	0.1060	0.2850	0.3940	0.4230	0.429
Output WS1	0.0060	0.1626	0.0553	0.2223	0.0000	0.5891	0.2389	0.182
Output WS2	0.0048	0.1238	0.0532	0.1708	0.0000	0.3530	0.1619	0.124
JULY								
Input C1	0.0350	0.0560	0.7830	0.1230	0.0220	0.2000	0.2140	0.205
Output WS1	0.1435	0.1448	0.2180	0.0043	0.1521	0.3417	0.1975	0.172
Output WS2	0.1140	0.1065	0.1749	0.0030	0.0866	0.2130	0.1257	0.118
AUGUST								
Input C1	0.0200	0.1230	2.0740	0.0460	0.0460	0.7110	0.3210	0.477
Output WS1	0.0720	0.0092	0.0540	0.0962	0.1823	0.0535	0.0483	0.074
Output WS2	0.0617	0.0081	0.0574	0.0973	0.1013	0.0357	0.0322	0.056
SEPTEMBER								
Input C1	0.0240	0.0590	0.4090	0.1990	0.0140	0.1510	0.2070	0.152
Output WS1	0.0114	0.0014	0.0344	0.0539	0.1593	0.1643	0.3919	0.117
Output WS2	0.0093	0.0013	0.0305	0.0431	0.0915	0.0787	0.2556	0.073
OCTOBER								
Input C1	0.0470	0.6040	1.0930	0.1260	0.0620	0.2530	0.1590	0.335
Output WS1	0.2300	0.0355	0.3324	0.6627	0.3352	0.4226	0.4471	0.352
Output WS2	0.1751	0.0279	0.2846	0.2274	0.2005	0.2697	0.2521	0.205
NOVEMBER								
Input C1	0.0290	1.0440	0.2350	1.7150	0.0490	0.2630	0.0370	0.482
Output WS1	0.2468	0.2839	0.9453	0.4676	0.3332	0.4186	0.2903	0.426
Output WS2	0.1867	0.2306	0.6355	0.3198	0.1888	0.1917	0.1814	0.276
DECEMBER								
Input C1	0.0160	0.1650	0.0260	0.9640	1.0850	0.2160	0.4870	0.532
Output WS1	0.3715	0.5319	0.5570	0.3271	0.5207	0.3915	1.0630	0.538
Output WS2	0.3096	0.2931	0.4181	0.2954	0.3564	0.2560	0.6880	0.374
ANNUAL SUMS								
Input C1	0.3800	.	7.6700	5.3250	6.8070	3.8700	2.6830	0.364
Output WS1	2.5657	.	3.5441	4.4391	4.1039	8.2642	6.5461	0.382
Output WS2	2.1523	.	2.6552	3.0123	2.4609	5.0581	3.9328	0.254

Table 6. Monthly Means and Annual Sums (kg/ha) for Phosphate.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	.	.	0.240	0.150	1.320	1.480	0.260	0.690
Output WS1	.	.	0.301	0.391	1.515	1.803	0.426	0.887
Output WS2	.	.	0.327	0.000	1.467	1.803	0.491	0.818
FEBRUARY								
Input C1	.	.	0.420	0.000	1.480	1.920	0.310	0.826
Output WS1	.	.	0.091	0.278	1.273	3.014	1.336	1.198
Output WS2	.	.	0.112	0.000	1.243	2.523	0.867	0.949
MARCH								
Input C1	.	.	0.360	0.110	1.140	1.890	0.250	0.750
Output WS1	.	.	0.083	0.223	1.184	2.713	0.540	0.949
Output WS2	.	.	0.130	0.118	1.119	2.527	0.496	0.878
APRIL								
Input C1	.	.	0.180	0.410	0.980	0.670	0.720	0.592
Output WS1	.	.	0.056	0.490	1.080	0.986	0.983	0.719
Output WS2	.	.	0.067	0.229	1.074	0.863	0.850	0.617
MAY								
Input C1	.	.	0.200	1.960	1.750	0.860	1.800	1.314
Output WS1	.	.	0.048	0.842	1.347	0.235	1.691	0.833
Output WS2	.	.	0.046	1.049	1.193	0.000	1.669	0.791
JUNE								
Input C1	.	.	0.540	2.940	0.910	0.720	1.360	1.294
Output WS1	.	.	0.016	1.056	0.000	0.273	0.489	0.367
Output WS2	.	.	0.011	1.152	0.000	0.236	0.425	0.365
JULY								
Input C1	.	.	0.370	0.890	1.650	1.600	0.730	1.048
Output WS1	.	.	0.075	0.014	0.376	0.884	0.424	0.355
Output WS2	.	.	0.069	0.018	0.259	0.750	0.398	0.298
AUGUST								
Input C1	.	0.070	0.090	1.830	1.330	0.870	1.020	0.868
Output WS1	.	0.002	0.003	0.322	0.286	0.084	0.124	0.137
Output WS2	.	0.004	0.005	0.323	0.305	0.094	0.099	0.138
SEPTEMBER								
Input C1	.	0.190	0.080	1.440	1.650	0.620	1.560	0.923
Output WS1	.	0.001	0.002	0.128	0.424	0.103	0.865	0.254
Output WS2	.	0.002	0.003	0.113	0.370	0.095	0.945	0.255
OCTOBER								
Input C1	.	0.140	0.100	0.860	1.070	1.060	1.510	0.790
Output WS1	.	0.004	0.051	0.837	0.684	0.000	0.987	0.427
Output WS2	.	0.016	0.046	0.784	0.805	0.015	1.037	0.451
NOVEMBER								
Input C1	.	0.030	0.000	2.940	0.840	0.350	0.460	0.765
Output WS1	.	0.080	0.095	1.236	1.066	0.034	0.585	0.516
Output WS2	.	0.044	0.000	1.335	0.828	0.018	0.592	0.470
DECEMBER								
Input C1	.	0.030	2.030	2.380	0.890	0.190	2.490	1.335
Output WS1	.	0.054	0.000	1.122	1.667	0.240	2.102	0.864
Output WS2	.	0.141	0.000	1.339	1.433	0.240	2.348	0.917
ANNUAL SUMS								
Input C1	.	.	4.610	15.920	15.030	12.220	12.470	11.196
Output WS1	.	.	0.823	6.938	10.902	10.372	10.552	7.505
Output WS2	.	.	0.818	6.450	10.096	9.165	10.217	6.946

Table 7. Monthly Means and Annual Sums (kg/ha) for Nitrate.

	1984	1985	1986	1987	1988	1989	1990	Monthly Average
JANUARY								
Input C1	0.540	.	0.380	0.810	1.020	1.250	1.250	0.88
Output WS1	0.680	.	1.074	0.769	1.785	1.510	1.643	1.24
Output WS2	0.443	.	0.354	0.319	1.570	1.360	1.185	0.87
FEBRUARY								
Input C1	0.750	.	8.180	0.620	1.520	1.750	0.590	2.24
Output WS1	0.880	1.060	3.740	1.070	1.520	2.101	1.833	1.74
Output WS2	0.545	.	3.631	0.816	1.437	1.861	1.227	1.59
MARCH								
Input C1	1.620	0.890	4.760	1.140	1.290	1.610	0.330	1.66
Output WS1	0.646	0.496	1.663	0.820	1.368	2.381	0.751	1.16
Output WS2	0.496	0.382	1.517	0.685	1.216	2.100	0.545	0.99
APRIL								
Input C1	1.410	0.580	4.960	2.010	0.900	0.780	0.680	1.62
Output WS1	0.567	0.419	0.897	1.367	1.029	0.575	1.069	0.85
Output WS2	0.627	0.371	0.786	1.195	0.996	0.472	0.779	0.75
MAY								
Input C1	0.820	1.990	0.690	2.940	1.580	2.010	1.510	1.65
Output WS1	0.517	0.340	0.543	1.421	1.224	0.805	2.033	0.98
Output WS2	0.339	0.345	0.269	1.452	1.131	0.706	1.246	0.79
JUNE								
Input C1	0.400	0.590	4.690	2.620	1.370	1.470	1.080	1.75
Output WS1	0.006	0.237	0.125	0.820	0.000	0.497	0.370	0.29
Output WS2	0.002	0.212	0.052	0.641	0.000	0.428	0.233	0.22
JULY								
Input C1	0.830	1.050	4.210	1.210	1.650	2.420	0.780	1.74
Output WS1	0.147	0.191	1.060	0.014	0.268	0.596	0.433	0.39
Output WS2	0.043	0.130	0.656	0.012	0.268	0.633	0.375	0.30
AUGUST								
Input C1	0.880	0.160	1.850	1.640	1.590	0.540	0.890	1.07
Output WS1	0.090	0.101	0.038	0.278	0.316	0.056	0.096	0.14
Output WS2	0.042	0.055	0.019	0.257	0.305	0.037	0.074	0.11
SEPTEMBER								
Input C1	.	0.990	1.090	2.060	1.650	0.920	1.450	1.36
Output WS1	.	0.005	0.032	0.164	0.336	0.140	0.845	0.26
Output WS2	.	0.003	0.014	0.144	0.302	0.106	0.756	0.22
OCTOBER								
Input C1	.	2.250	3.900	1.530	1.660	1.180	0.890	1.90
Output WS1	.	0.032	1.586	0.958	0.726	0.829	1.206	0.89
Output WS2	.	0.019	1.053	0.845	0.595	0.494	0.932	0.66
NOVEMBER								
Input C1	.	.	1.120	2.840	0.950	1.490	0.510	1.19
Output WS1	.	1.597	1.112	1.556	0.992	0.774	0.695	1.12
Output WS2	.	0.408	1.096	1.357	0.815	0.426	0.592	0.78
DECEMBER								
Input C1	.	0.470	0.540	1.570	0.890	0.720	1.770	0.99
Output WS1	.	0.955	1.074	1.132	1.601	0.799	3.459	1.50
Output WS2	.	1.161	0.946	0.985	1.204	0.402	2.747	1.24
ANNUAL SUMS								
Input C1	.	.	36.370	20.990	16.080	16.150	11.730	18.05
Output WS1	.	.	12.944	10.368	11.167	11.063	10.552	10.56
Output WS2	.	.	10.390	8.709	9.840	9.025	10.690	8.47



